Depositional Units in Fluvio - Lacustrine Reservoirs and Their Use as Equilibrium Regions: A Case Study in San Jorge Basin, Argentina*

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Abstract

Geologic characterization and static modeling of an oil reservoir set in Upper Cretaceous fluvio-lacustrine deposits were performed to analyze the behavior of different depositional units as equilibrium regions. Using SP, resistivity and conductivity logs from more than 500 wells, the most important shale levels with lateral continuity were correlated resulting in 30-50 m thick cycles characterized by stacking of sandstone beds with normal, reverse or aggradational patterns. The variation in gradational patterns and lithofacies, vertical and lateral changes respectively, are interpreted as caused by local changes in a fluvial channel belt environment, e.g. transition between main channel to levee and floodplain deposits. Each of these stacking patterns was limited at its top and bottom by a shaly interval acting as a fluid barrier.

Fluid distribution within each unit at the beginning of field development was evaluated using completion well tests and petrophysics, leading to the recognition of capillary-gravity equilibrium with the presence of a primary gas cap in the highest parts of the structure, an oil zone in the middle and water in the lowest sections, always within faulted compartmentalization blocks of the same unit. This fluid distribution behavior is an indication of the degree of connectivity between the different reservoir units within each depositional unit or cycle.

Based on published studies, a correlation between reservoir connectivity and net-to-gross ratio (NTG) was established. However, evidence from dynamic parameters is needed to assess the degree to which this connectivity contributes to improve recovery and waterflood sweep efficiency. Along these lines, some conceptual, mechanistic dynamic simulation results are also presented showing that differences in static pressure between connected sandstone bodies (measured by RFT for example) can be quite large depending on the effective transmissibility of the connection and the production-injection history. Therefore, a general conclusion of the present study is that static connectivity leads to equilibrated initial fluid distributions because this is achieved in geologic time scales, whereas connectivity that is effective for reservoir depletion and sweep (at development time scales) needs to be evaluated using more complex tools such as pressure tests, tracers, and dynamic simulation.

Selected References

Bridge, J.S., G. A. Jalfin, and S.M. Georgieff, 2000, Geometry, lithofacies, and spatial distribution of Cretaceous fluvial sandstone bodies, San Jorge Basin, Argentina; outcrop analog for the hydrocarbon-bearing Chubut Group: JSR, v. 70/2, p. 341-359.

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Depositional Units in Fluvio - Lacustrine Reservoirs and Their Use as Equilibrium Regions: A Case Study in San Jorge Basin, Argentina

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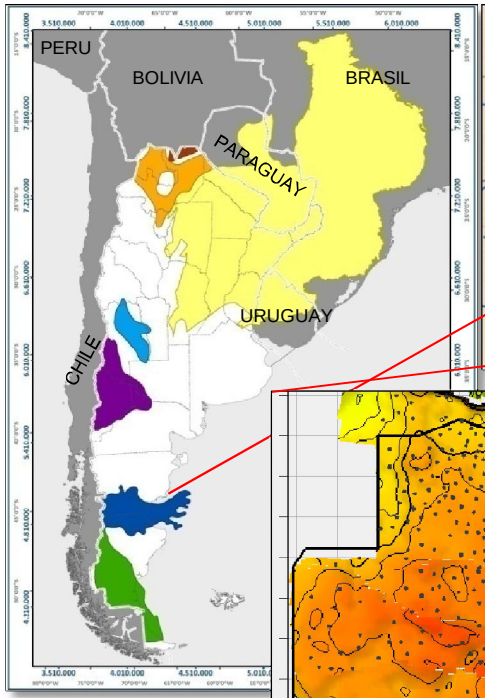
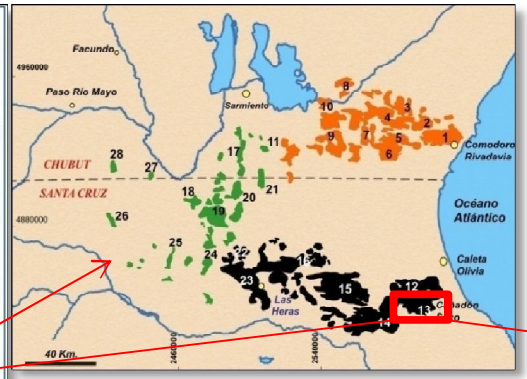
Session title: **Mature Fields: New Ideas in Oil Plays**

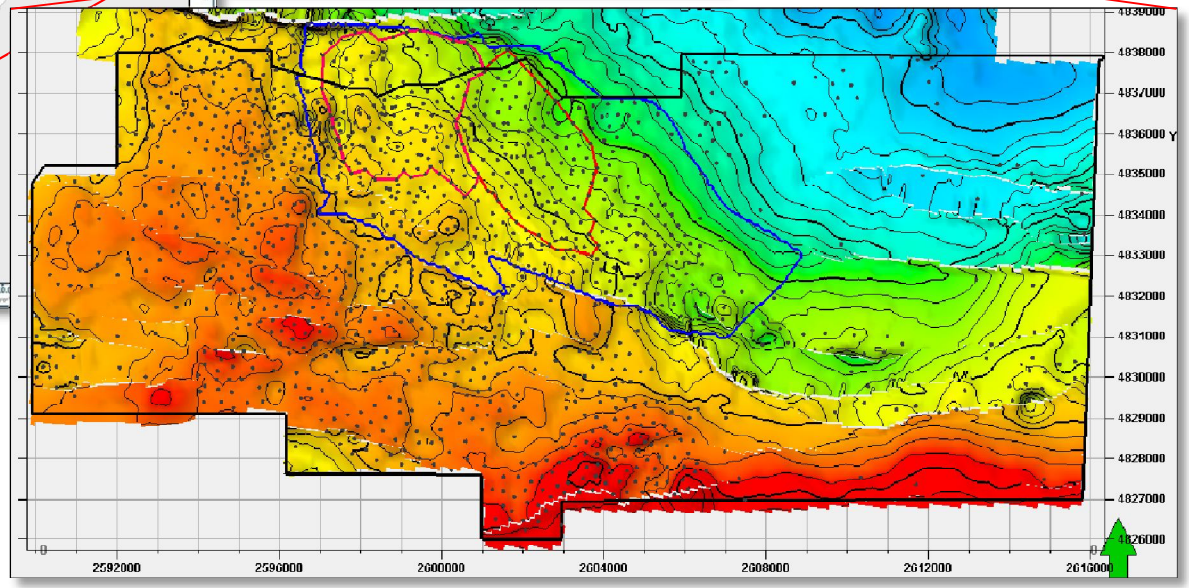
Golfo San Jorge Basin Cañadón León field Cañadón Seco Fm

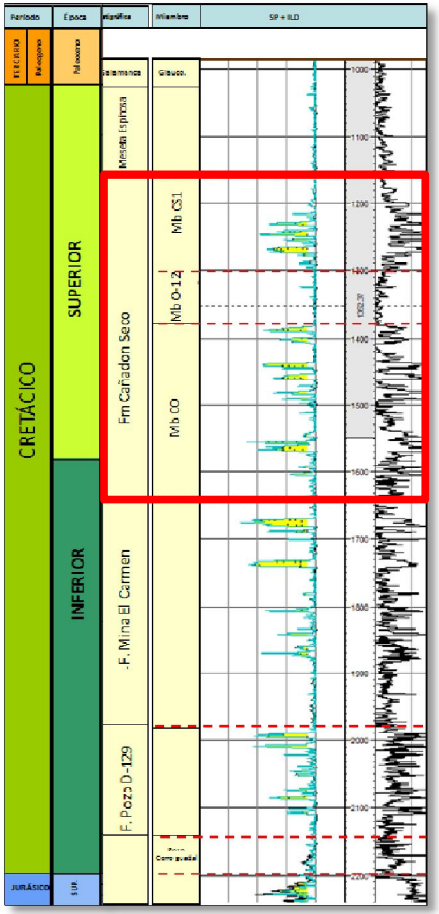




Characteristics

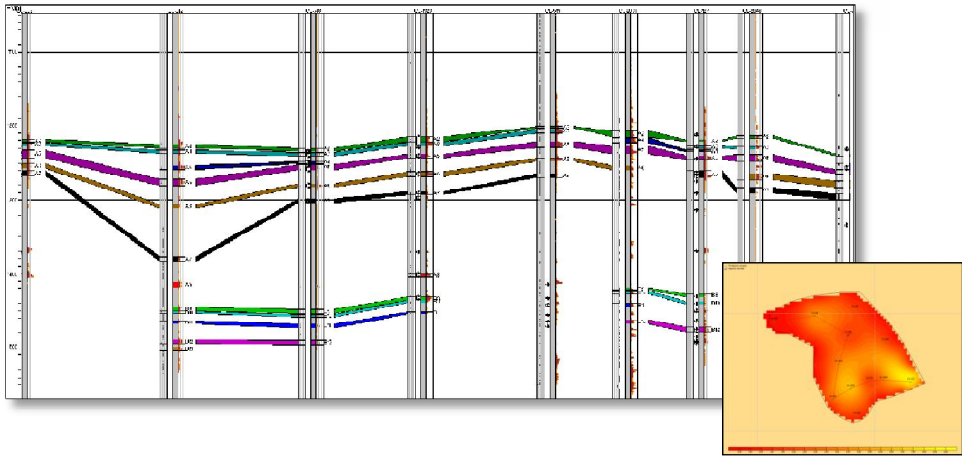
- Oil production: 970 m³/d
- WCUT ≈ 89%
- Drilled wells: 1311 (Prod +WI)
- In production since 1955
- Waterflooding since 1967
- Original pressure: 105 kg/cm2 at ~1000 mbsl
- Bubble pressure: 85 kg/cm2
- Trap: Structural (>)- Stratigraphic (<)
- Well spacing: 250 m

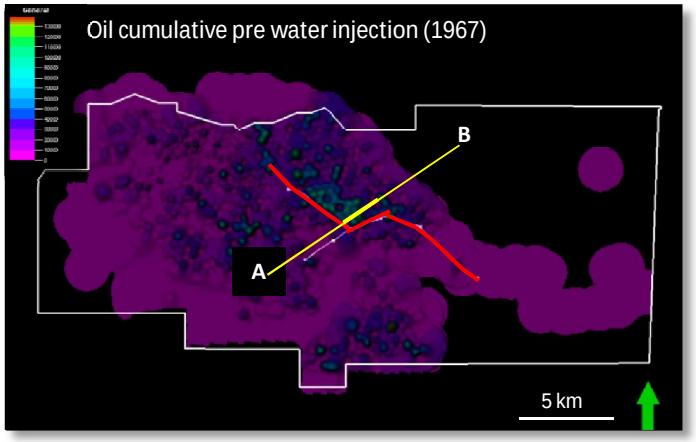


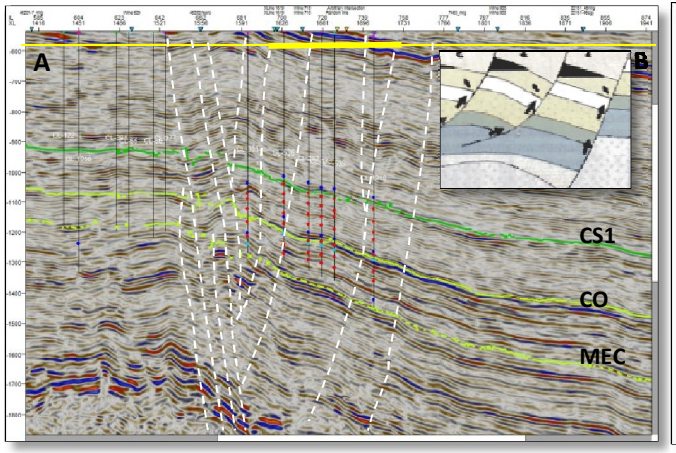


Former static model and Historic field production performance

- Capa-capa “model”: “Sand bodies” identified in e-logs and correlated based on completion and pressure tests.
- Successful during early development, but no production history match. Anomalous RF.
- Concentration of highly productive wells near main faults supports the importance of structural control over production.
- Also water cumulative (pre WI) match with main faults.
- Uncertainty in vertical and horizontal connectivity.





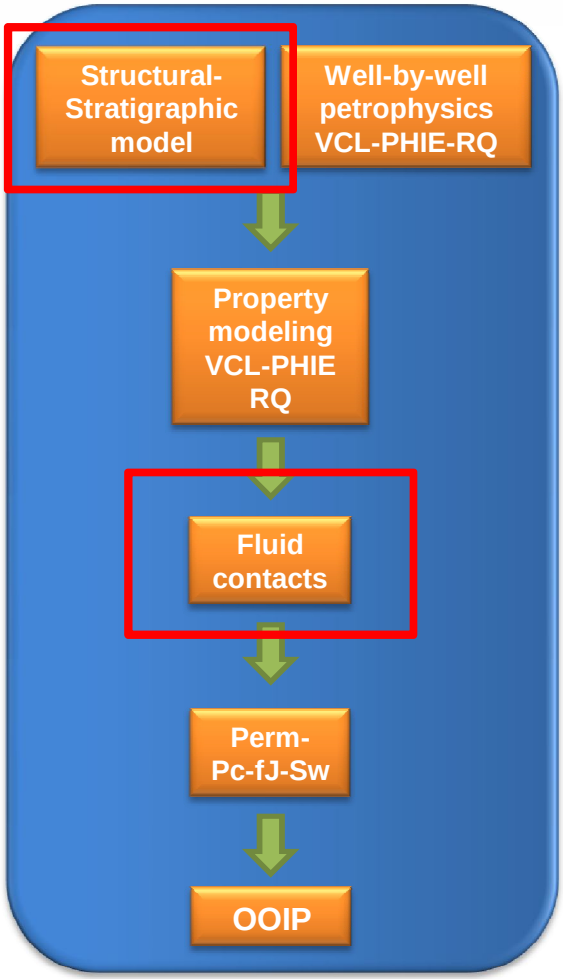


Objectives

1. **Secondary recovery optimization for Cañadón Seco Fm. reservoirs.**
2. **To develop a valid 3D model methodology for this reservoir type and evaluate its feasibility for better estimation of Reserves.**

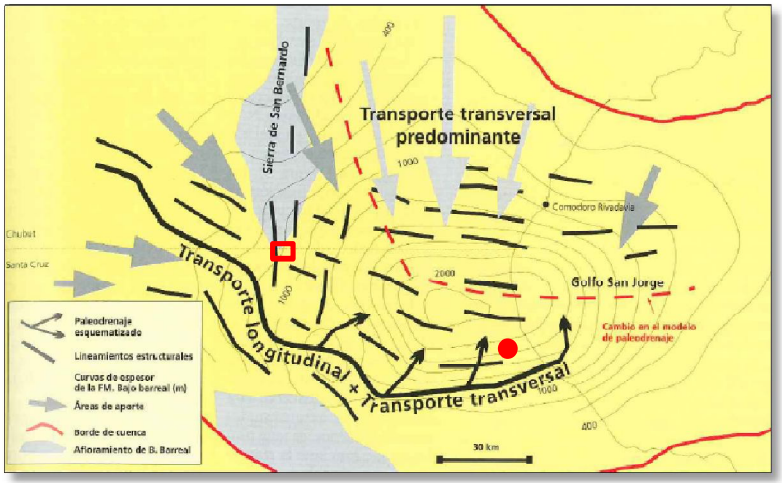
Cañadón León static model workflow

1. **Conceptual model**
2. **Structural and Stratigraphic model.**
   - **Faults and horizons.**
3. Well petrophysics.
   - VCL, PHIE (from logs and synth) y RQ
4. Geocellular model and property modeling
   - VCL, PHIE y RQ
5. **Fluid distribution.**
   - **Contacts: LKG, LKO y HKW**
6. Complementary reservoir properties.
   - K, J (Leverett), Sw
7. Volume calculation, property grids and maps

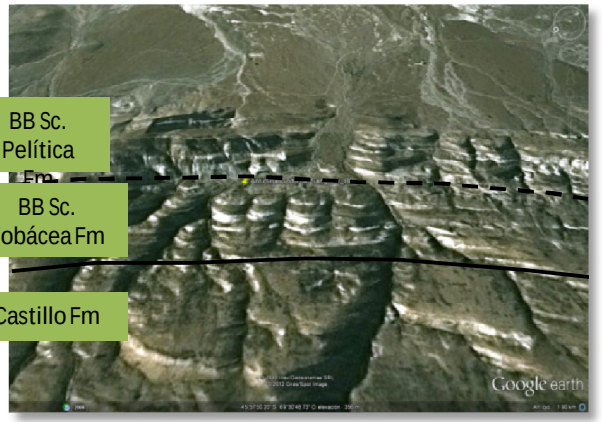


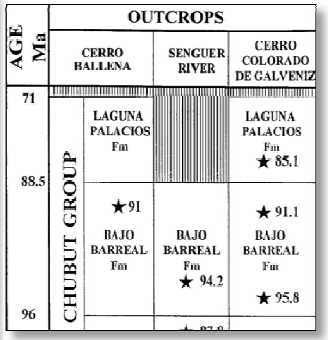
Cañadón Seco Fm Conceptual model

- Fluvio-lacustrine (+volcaniclastic) deposits, within a Sag period, with active syndepositional faulting.
- Regional basin-centered sediment dispersion, locally transversal fault-controlled sediment dispersion (Southern flank).
- 30-50 mts thick cycles of amalgamated channel fills, limited on top and bottom by flood plain dominated intervals, with continuity within major faults. They were interpreted as Low and High accommodation systems tracts under fluvial upstream conditions following Catuneanu, 2005.
- In outcrop, this depositional units and channel deposits amalgamation is confirmed

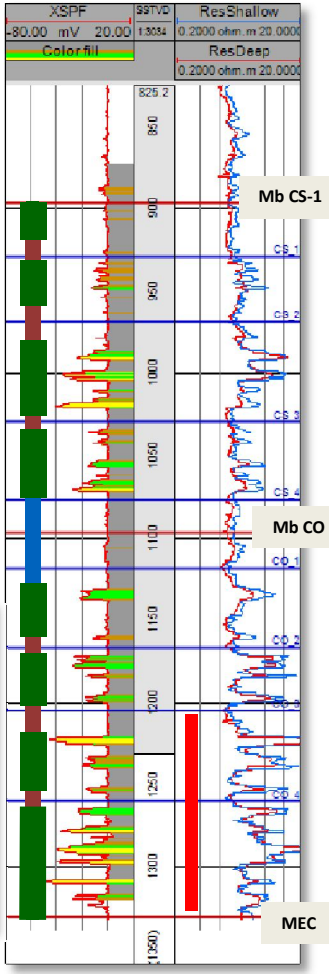


Hechem, 1996. Basin shape, BB Fm thickness y sediment paleotransport

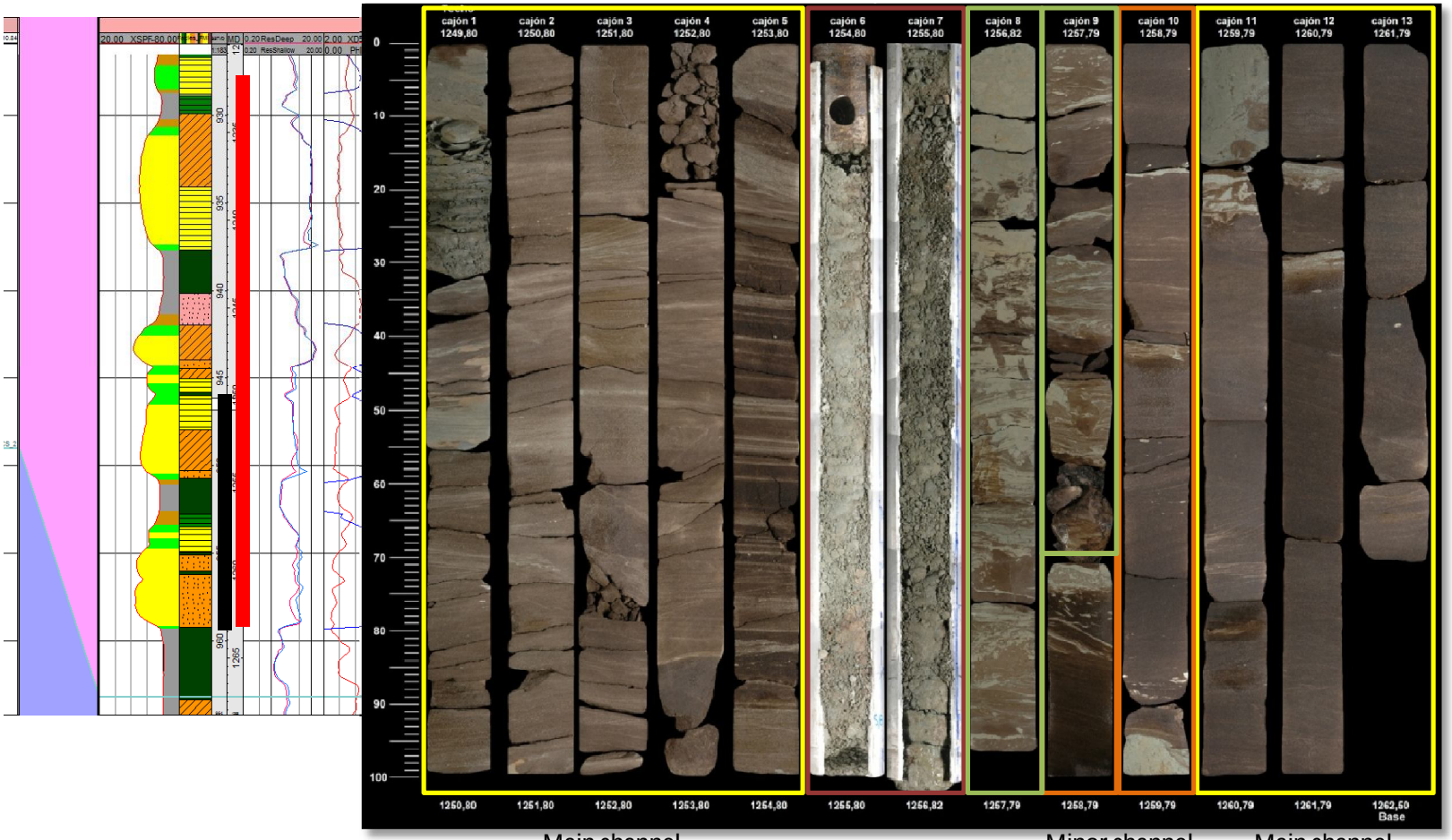




Bridge et al., 2000.
Cañadón Seco Fm ~5 Ma



Core



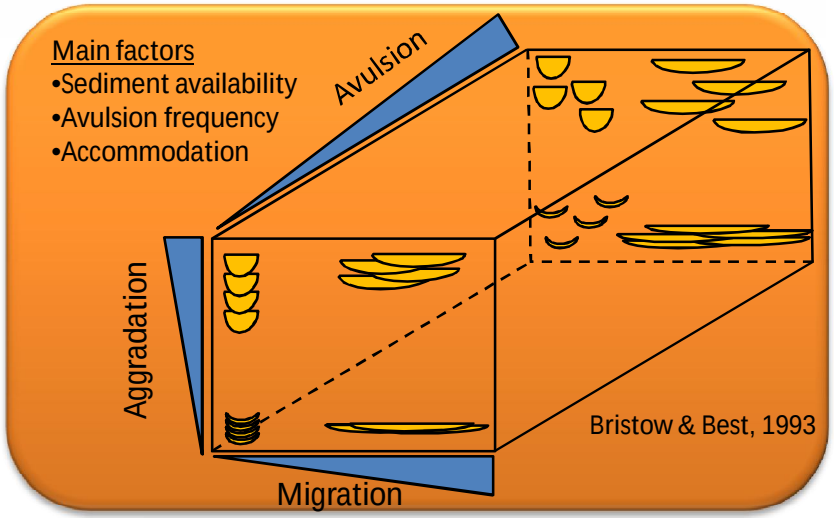
Main channel deposit

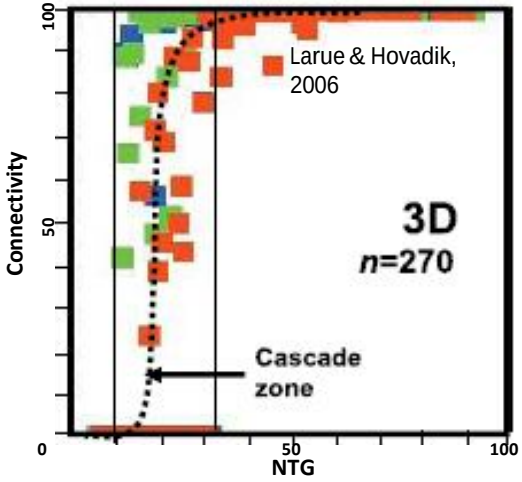
Minor channel deposit

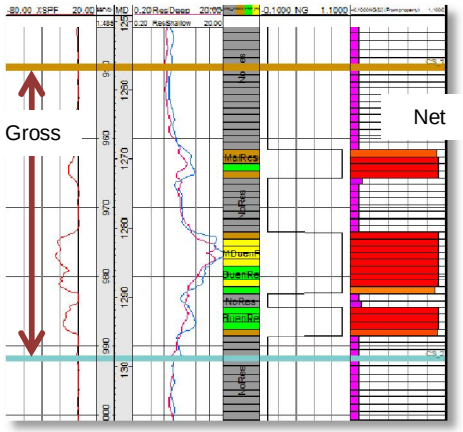
Main channel deposit

Aplication of L-H Systems tracts as oil reservoirs – NTG and Connectivity

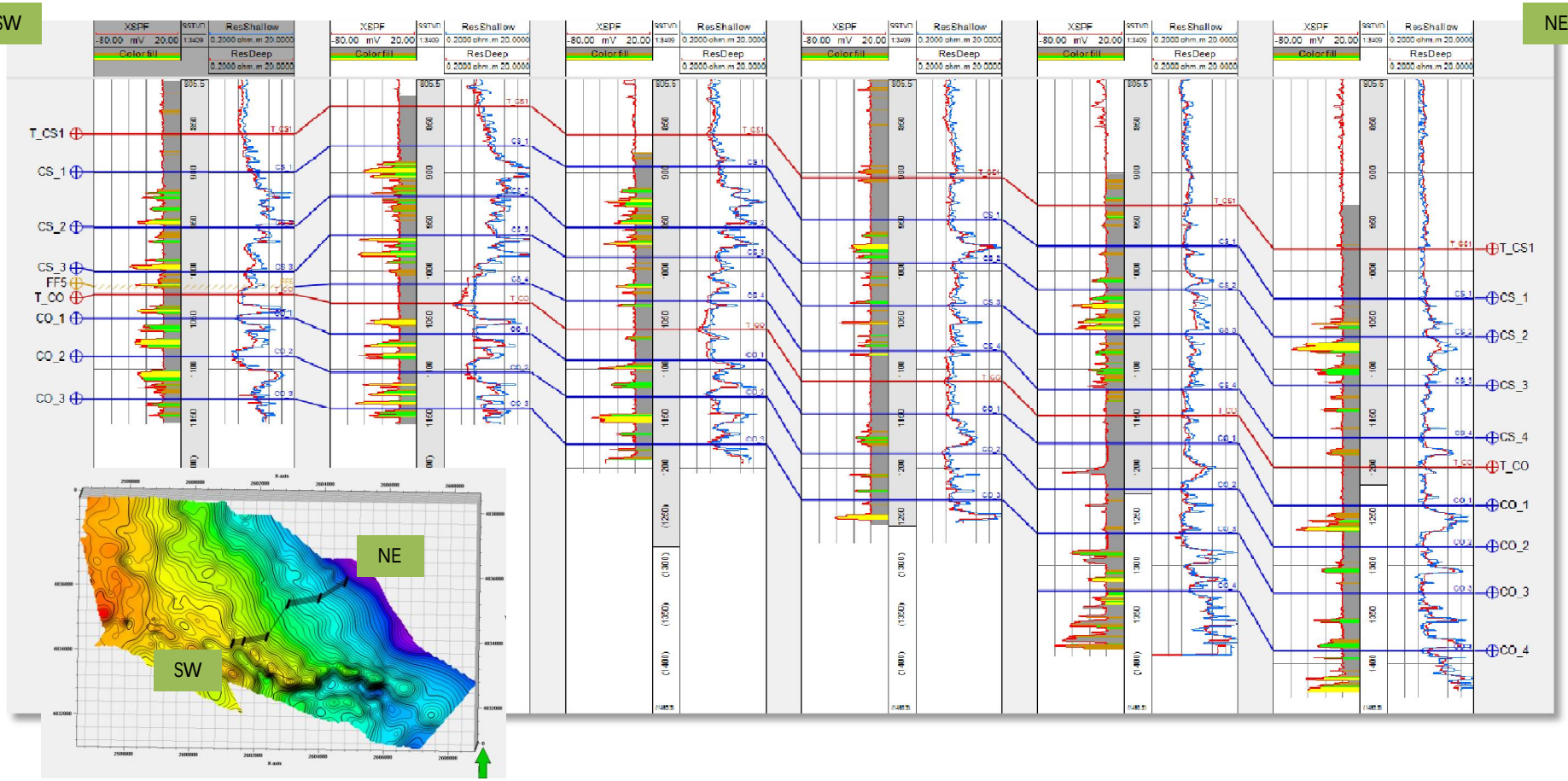
- From the oil productivity point of view, **Low accommodation *systems tracts*** represent the main target due to its connectivity.
- Depending on how connected they are they can be considered as **"GTS Equilibrium regions"** from the dynamic point of view, in which geologic time (My) give the chance to establish a capillary-gravitational equilibrium of fluids. This could be tested by completion fluid tests.
- Increasing connectivity **"DTS Equilibrium regions"** could be reached. In this case, a whole group of sand bodies could be drained being only some of them completed and perforated. This could be evaluated with pressure and saturation data over new wells.
- Larue & Hovadik (2006) presented an evaluation of how "connectivity" (drainage) is influenced by fluvial deposits morphology and "Systems tracts NTG".





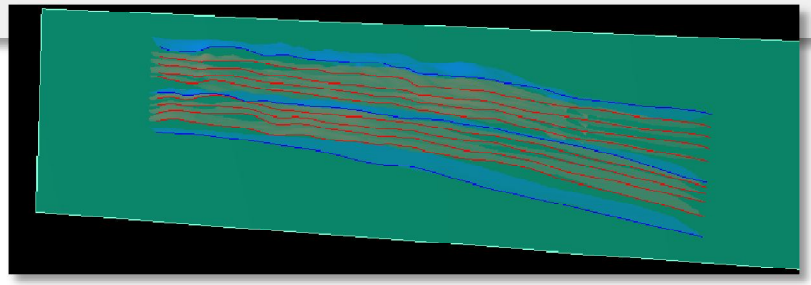


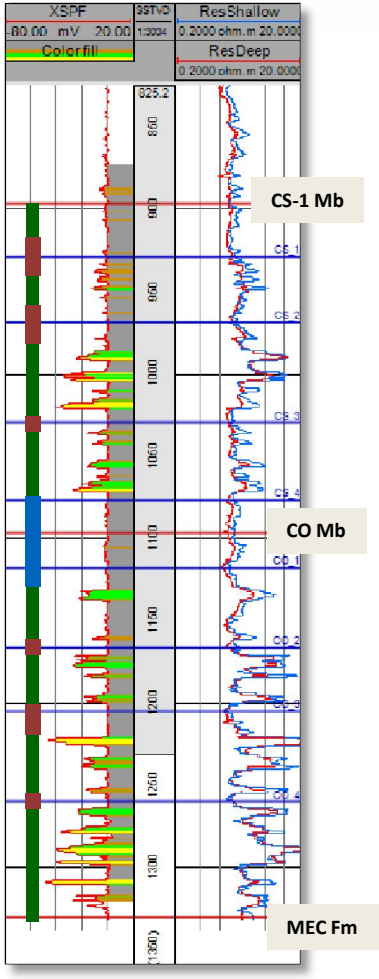
Stratigraphic correlation – Depositional units



Faults and horizons model

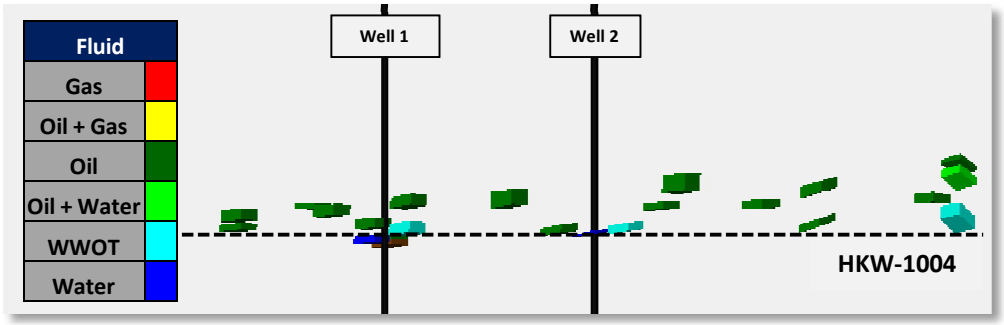
- Depositional units
- Fault segments
- 3D Grid

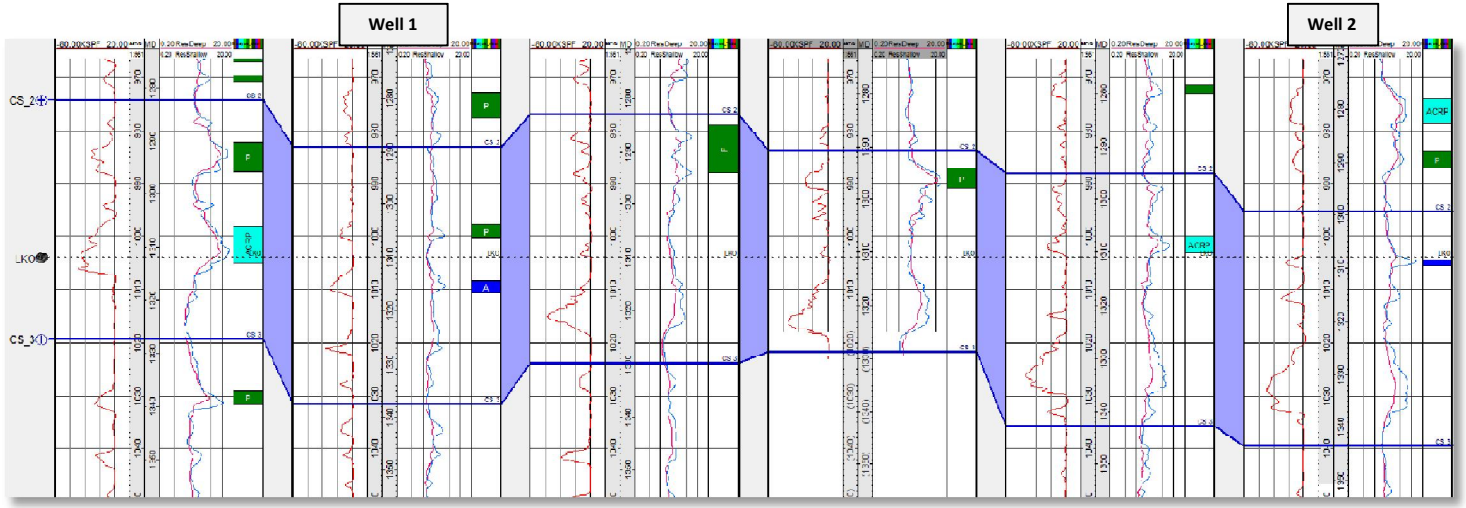


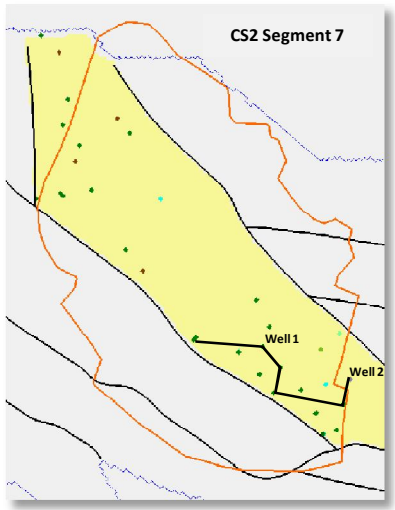


Original fluid distribution. LKG, LKO and HKW contacts

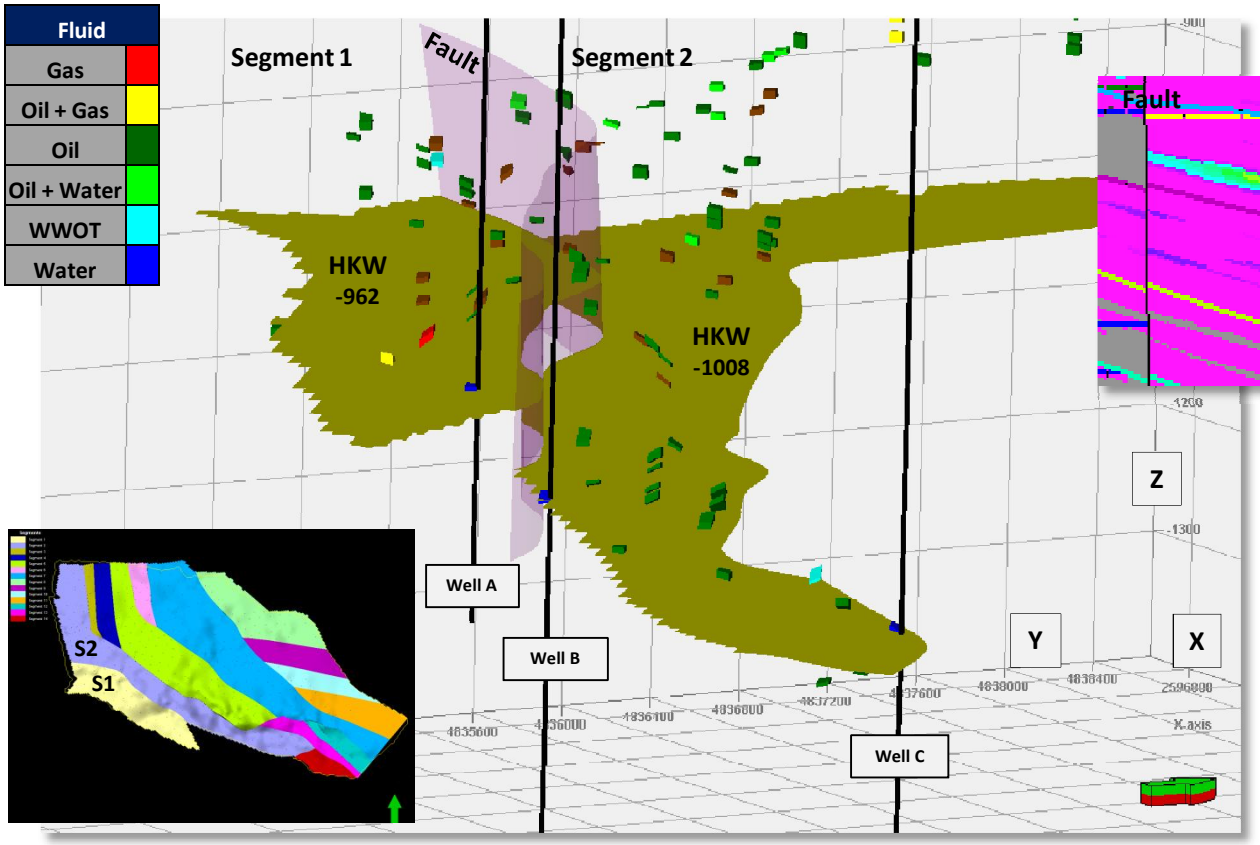
- Fluid contacts were defined based on completion fluid tests within depositional unit and fault segment (“compartments”).
- Only fluid tests that guarantee original reservoir information were considered.
- Based on that, the following completion tests were discarded:
  - Water tests from completions after 1970.
  - Tests with less than 200 l/h.
  - Gas tests in well developed areas.
  - Multi-layered tests.

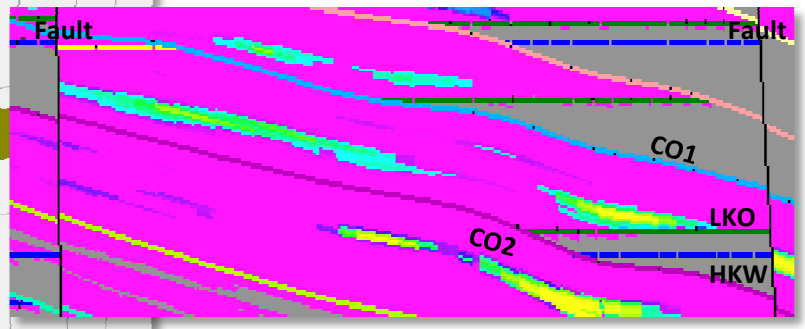






Original fluid distribution. LKG, LKO and HKW contacts



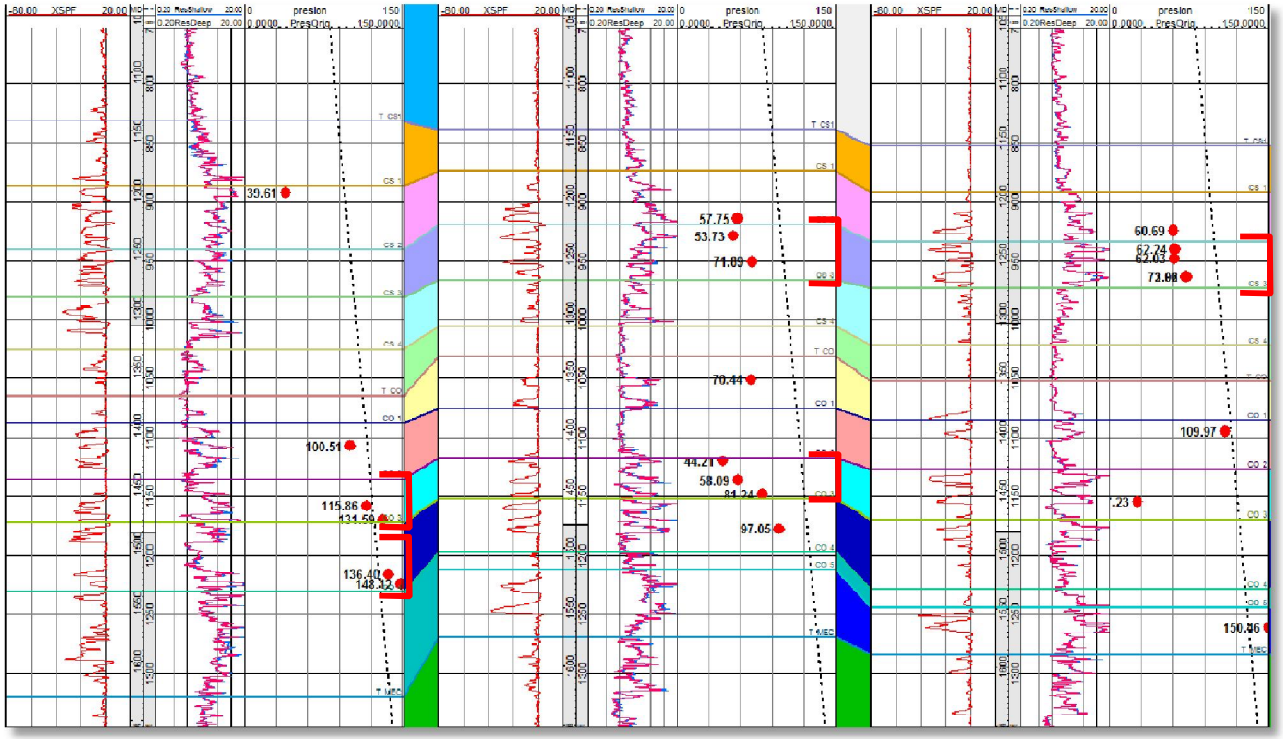


- Example of fluid distribution within a single depositional unit with different contacts by fault segment

- Fluid contacts for 140 compartments (the combination of depositional units and faulted blocks) were defined
- In most of the cases only LKO and HKW were recognized
- In order to be conservative with volume calculations, LKO (taken as coincident with FWL) was considered when the 3D grid was populated with oil saturation.

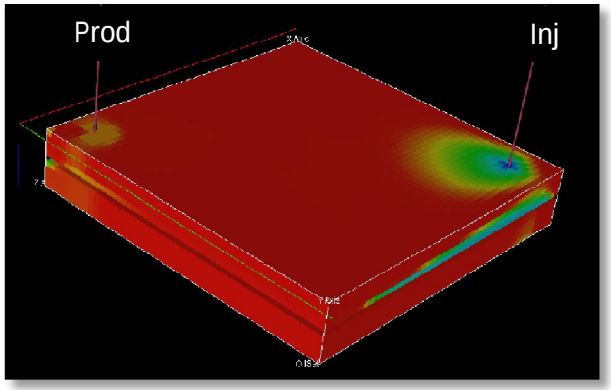
Connectivity at development time scale – RFT Pressure tests analysis

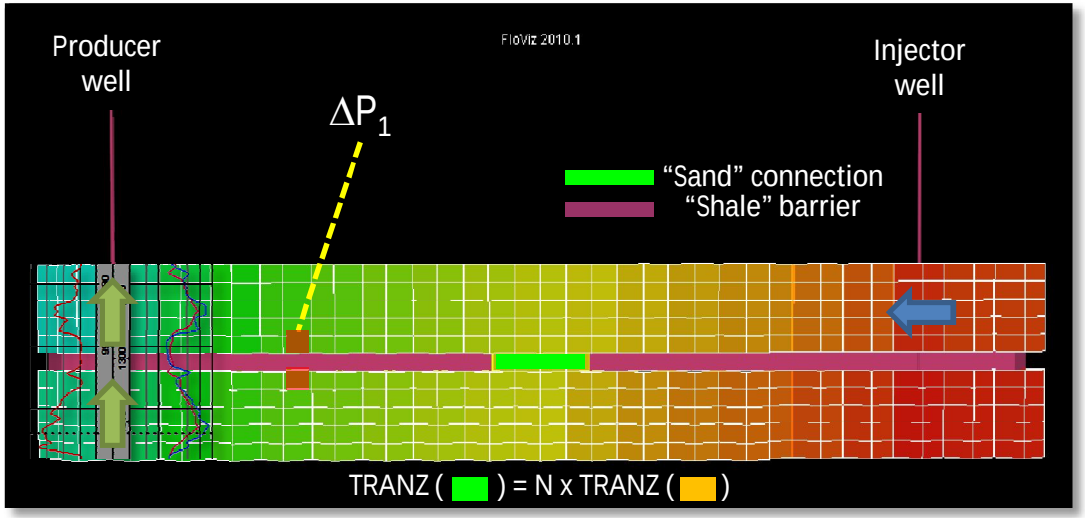
- Available pressure data for evaluating connectivity between sand bodies is scarce.
- Dashed line is an estimation of the original reservoir pressure.
- From this data, it was recognized that bodies from the same depositional unit were not in hydrostatic equilibrium
- Is that a direct evidence of a disconnection between these sand bodies?

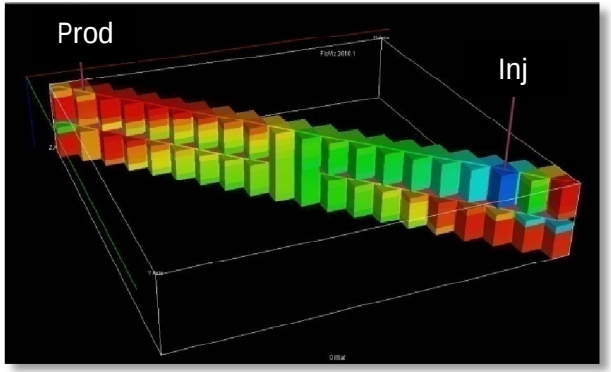


Conceptual models for vertical connectivity evaluation

- These models were performed in order to evaluate the effect in vertical connectivity of a couple of amalgamated sand bodies within a depositional unit.
- The conceptual model was built with a “connection” represented by a rectangle placed in the center of the model. During several simulations Z-direction transmissivity (TRANZ) of this connection was modified in order to evaluate different connectivity degrees.
- Producer well is completed in both bodies while Injector is only completed in the upper one.
- In these models, pressure differences (ΔP_1) and volumes produced by both sand bodies were evaluated.



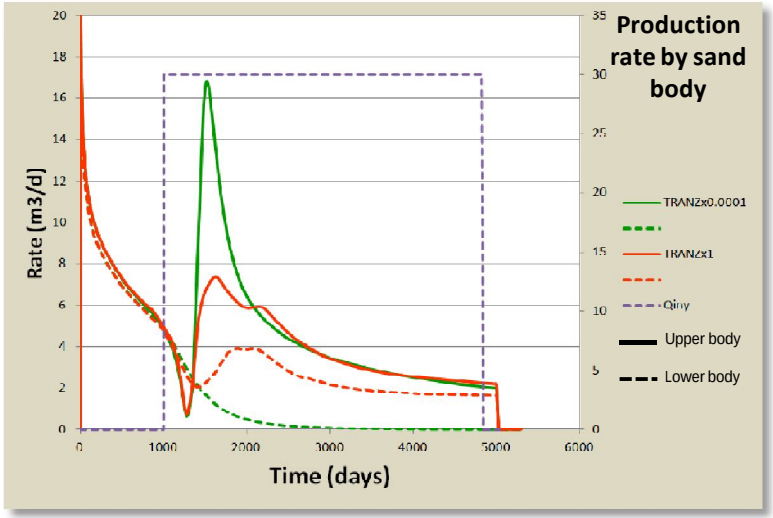


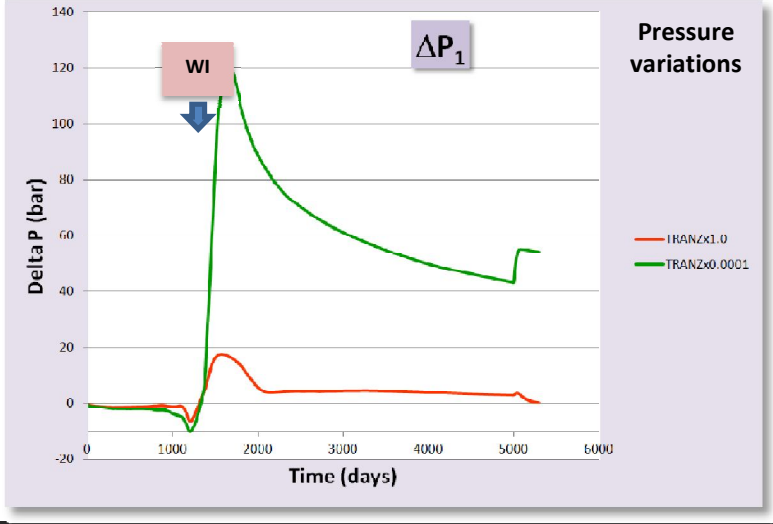


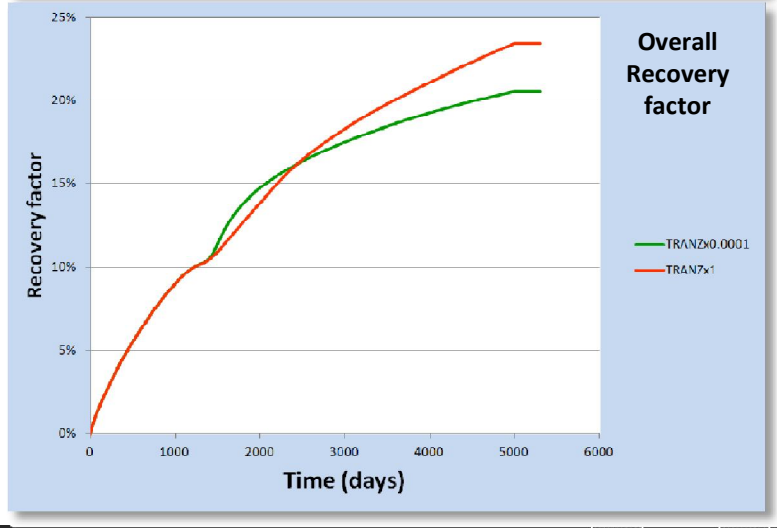
Conceptual models for vertical connectivity evaluation - Results

- End-member cases from TRANZ variations simulations are discussed:

1. Pre WI ΔP_1 is showing a typical hydrostatic trend. At the beginning of WI a sudden increase occurred. ΔP_1 magnitude is highly sensitive to the different TRANZ cases.
2. In terms of **production rate by sand body**, when transmissivity is good both bodies have secondary recovery response. In the low TRANZ case the lower body follows a primary development trend.
3. Finally the **overall recovery factor** turns out to be higher with the increase of the connectivity.

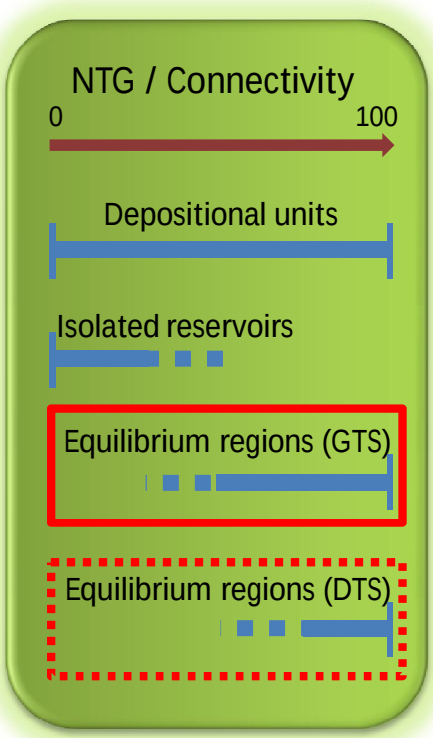


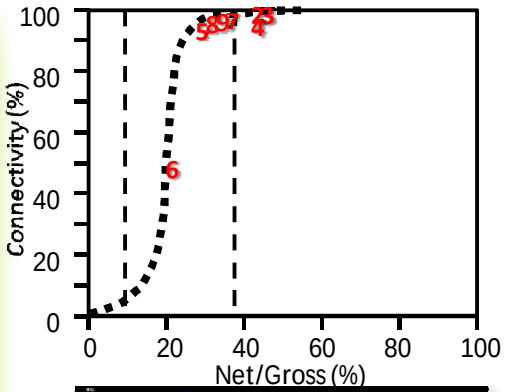


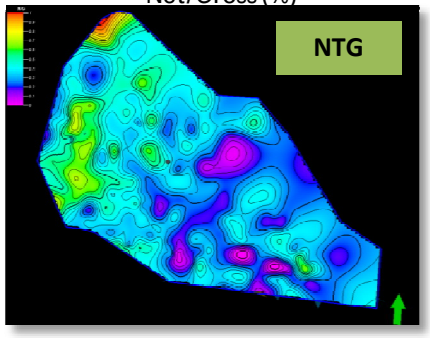


Discussions and Conclusions

- It is possible to subdivide Cañadón Seco Fm into **depositional units**.
- More important units are interpreted as **Low accommodation systems tracts**, composed by channel belts with amalgamated channels, overbanks and floodplain deposits.
- The feasibility of determining fluid contacts by compartments indicates that depositional units could be considered as **Equilibrium regions at geological time scale**.
- Most of the LAST presented **a NTG higher than 30%** what is in line with Larue & Hovadik (2006) for high connected reservoirs. In the cases when NTG is below the threshold suggested (~<20), there could exist stratigraphic traps.
- Observation of formation pressures out of equilibrium in sands within a single LAST at development time scales **does not imply lack of connectivity between sand bodies**. However, this may imply that connections are tortuous and may not allow, for example, high sweep efficiency in waterflooding.







Proposal for validating these ideas

Field pilot

Dynamic simulation

YPF

Thank you very much

Challenge for Mature fields:

Update and validate historic concepts to new ideas and models.

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